RESEARCH DEPARTMENT

THE USE OF A HIGH-GAIN TELEVISION TRANSMITTING AERIAL IN A POPULOUS AREA WITH PARTICULAR REFERENCE TO THE CRYSTAL PALACE STATION

Report No. E-072

(1960/15)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

THE USE OF A HIGH-GAIN TELEVISION TRANSMITTING AERIAL IN A POPULOUS AREA WITH PARTICULAR REFERENCE TO THE CRYSTAL PALACE STATION

Report No. E-072

(1960/15)

G.H. Millard, B.Sc., A.Inst.P.
G.D. Monteath, B.Sc., A.Inst.P., A.M.I.E.E.
D.J. Whythe, B.Sc.(Eng.), A.M.I.E.E.

W. Proctor Wilson

(W. Proctor Wilson)

Report No. E-072

THE USE OF A HIGH-GAIN TELEVISION TRANSMITTING AERIAL IN A POPULOUS AREA WITH PARTICULAR REFERENCE TO THE CRYSTAL PALACE STATION

Section	Title	Page
1	INTRODUCTION	1
2	SOME METHODS OF GAP FILLING	2
3	THE EFFECTIVE VERTICAL RADIATION PATTERN AT FINITE DISTANCE	3
4	THE EFFECT OF REFLECTION AT THE GROUND	4
5	THE CRYSTAL PALACE AERIAL	5
6	HORIZONTAL RADIATION PATTERNS	7
7	CALCULATION OF FIELD STRENGTH NEAR THE GROUND	8
	7.1. Method of Calculation	8
	7.2. Performance in the Absence of Gap Filling	10
	7.3. Initial Method of Gap Filling	14
8	PERFORMANCE OF THE AERIAL WITH GAP FILLING	15
9	MODIFICATIONS	19
10	PERFORMANCE AFTER MODIFICATION	21
11	CONCLUSIONS	21
12	ACKNOWLEDGMENTS	23
13	REFERENCES	23

May 1960

Report No. E-072

(1960/15)

THE USE OF A HIGH-GAIN TELEVISION TRANSMITTING AERIAL IN A POPULOUS AREA WITH PARTICULAR REFERENCE TO THE CRYSTAL PALACE STATION

1. INTRODUCTION

In order to make the most of the transmitter power at a television transmitting station it is advantageous to use a high-gain aerial, usually consisting of a number of tiers. This increases the field strength in the more distant parts of the service area while reducing the radiation of energy upwards, where it is not wanted, and downwards to areas where the field strength would otherwise be greater than necessary.

The performance of a transmitting station is often expressed in terms of the effective radiated power (e.r.p.), i.e. the power that would require to be radiated by a half-wave dipole in order to give the same field strength in horizontal directions. Any e.r.p. required may be achieved with various combinations of aerial gain and transmitter power, the best choice being determined by an economic balance. In general, the greater the e.r.p. required, the greater are both the transmitter power and the aerial gain in the optimum combination.

Assuming that the tiers of an aerial are identical and equally spaced, the greatest gain is achieved when the radiating currents in all the tiers are in phase. The magnitudes of the currents giving maximum gain are not quite equal,[1] but the loss of gain due to the use of equal currents is negligible in practice.

Fig. 1 shows the vertical radiation pattern (v.r.p.) of a typical 8-tier aerial. This will be seen to comprise a main lobe directed horizontally and minor lobes above and below it, the lobes being separated by minima, each of which is associated with an annulus in which the field strength is much less than that elsewhere in the vicinity. When the gain of the aerial is low — for example, as at Sutton Coldfield where there are only two tiers — the directions of all the minima are steeply inclined to the horizontal so that they affect only a small area surrounding the station. With a high-gain aerial the area affected is greater. For the v.r.p. of a typical 8-tier aerial illustrated in Fig. 1 the radius of the outermost annulus, caused by minimum A, is about eight times the height of the mid-point of the aerial. Nevertheless, in the United Kingdom, few viewers would normally be affected since stations are usually built in rural areas. In the U.S.A., however, transmitting stations are often sited in towns, and at an early stage in the development of the American television service it was found that unsatisfactory reception was caused by the minima in the v.r.p. Steps are usually taken to avoid this difficulty.[2]

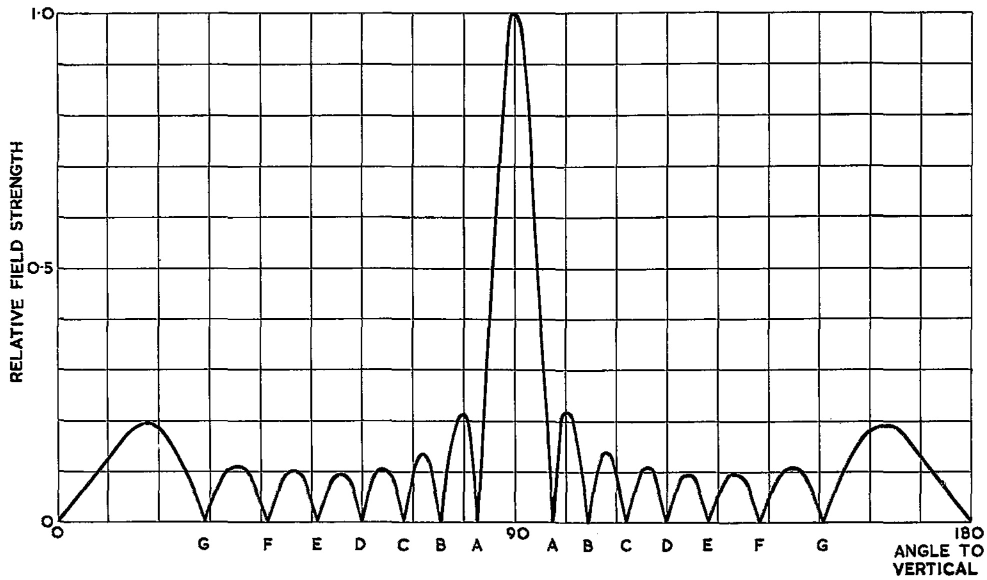


Fig. 1 - Vertical radiation pattern of a typical 8-tier aerial: all tiers fed with equal co-phased currents

In Band I, at least, it is highly improbable that the field strength will ever be inadequate anywhere in the vicinity of the transmitting station; the objection to a v.r.p. with sharp minima is that signals may be distorted. For example, if the field strength, though adequate, is much less than that in neighbouring areas, multi-path propagation is likely to be troublesome, leading to enhancement of ghost signals. Moreover, the v.r.p. will change slightly with frequency, and as a result the frequency response may be very non-uniform and the ratio of the strengths of the sound and vision carriers may be abnormal.

It is always possible to modify the v.r.p. of the transmitting aerial in order to fill in the minima to any extent that seems desirable (this procedure may be termed "gap filling"), but the price to be paid is a loss of aerial gain. In other words, many viewers, including those on the fringe of the service area, must suffer a small reduction in field strength in order to avoid intolerable distortion for a few viewers who live near to the transmitting station. Only experience can show how far it is necessary to go; in the B.B.C., experience was obtained for the first time following the completion of the 8-tier aerial at Crystal Palace. The primary purpose of this report is to record the experience gained at that station, but in the first place it is desirable to discuss the general principles involved.

2. SOME METHODS OF GAP FILLING

The only methods of gap filling to be considered in this report amount to modifying the distribution of radiating currents in amplitude and phase. The task of determining the amplitudes and phases required can be approached in either of two ways:

(i) The aerial is regarded as an aperture distribution which is determined in terms of the Fourier transform of the required radiation pattern.* This method leads to all the tiers of the aerial being fed differently.

(ii) The v.r.p. obtained with all tiers fed equally and in phase is taken as a starting point, and the simplest changes are made to provide the degree of gap filling required.

Of these, (i) is probably the more suitable for use in Band IV or Band V where a large number of tiers may be used (practical designs incorporate up to 54 tiers), and where the modification of the v.r.p. must be considerable. In these bands the relative bandwidth of the transmission is small and this eases the task of feeding such a large number of tiers differently. Method (ii) appears to be the better in Band I, where it is unusual for more than eight tiers to be employed. Either method might be used in Band III.

In what follows, only method (ii) will be considered.

It is convenient to define the phase associated with the v.r.p. with reference to that of the field that would be radiated by an isotropic source at the centre of the aerial. Applying this convention to the v.r.p. shown in Fig. 1, the phase is constant over each lobe, adjacent lobes being in antiphase. It follows that the minima could be filled in by installing an additional tier at the centre of the aerial and feeding it in phase quadrature to the other tiers. This method would, however, be inefficient, in addition to requiring an additional tier, since there is an appreciable waste of energy; for example, the central tier would radiate half its energy upwards where it is not wanted. A better method would be to modify the amplitudes and phases of the radiating currents in the two central tiers of the original aerial by superimposing upon them additional components of current. These would be so chosen that in isolation they would produce a v.r.p. which is tilted downwards and which is in phase quadrature to the primary v.r.p. Another method is to feed all tiers of the aerials in phase, but with unequal amplitudes. If the amplitudes are tapered from one end of the aerial to another, all the minima are filled in to some extent. This method is quite efficient but rather complicated. By feeding the halves of the aerial with unequal powers alternate minima may be filled. These include the minimum nearest to the main lobe (A in Fig. 1), which is usually the most important since it corresponds to the outermost, and hence the largest, area affected.

3. THE EFFECTIVE VERTICAL RADIATION PATTERN AT FINITE DISTANCE

Up to this point the problem has been considered in terms of the v.r.p., i.e. the free-space field at a great distance as a function of the zenithal angle, ignoring ground reflection, but two modifications to this simple representation must be considered. In the first place, the distances involved in practice may not be sufficient to be regarded as infinite. Unfortunately, this will usually be the case in Band I, though seldom in Band III and probably never in Bands IV and V. Secondly, as will appear, the effect of reflection at the ground cannot be ignored.

*Unpublished report by Gabriel Laboratories.

Referring to Fig. 1, the minima arise as follows:

A, C, E and G: the two halves of the aerial (each comprising four tiers) produce fields that are equal and in antiphase.

B and F: any two adjacent quarters of the aerial (each comprising two tiers) produce fields that are equal and in antiphase.

D: any two adjacent tiers produce fields that are equal and in antiphase.

One way in which finite distance modifies a v.r.p. such as that shown in Fig. 1 is illustrated in Fig. 2. Suppose that P is a point corresponding to minimum A, at which the contributions from the two halves of the aerial are in antiphase. Now it will be seen that the angle α_U is greater than α_L; in other words, in so far as the point P is concerned the signal from the upper half of the aerial is received from a greater angle to the maximum of the v.r.p. than is the signal from the lower half. It follows that the contribution to the field strength from the upper half will be weaker than that from the lower half. This effect will be accentuated slightly by the fact that UP is greater than LP. Since the contributions are unequal in magnitude, they cannot cancel one another completely and the minimum in the v.r.p. will be partially filled in. The discontinuous change of phase by 180° between adjacent lobes is, of course, converted to a continuous change.

The argument outlined above may be extended to show that all the minima will be partly filled. They will also be displaced slightly from the directions indicated by the v.r.p. For example, the fact that minimum A will be displaced may be inferred from Fig. 2 by observing that $UP - LP$ is not quite equal to $UL \sin\alpha_C$. The effects described depend on the physical length of the aerial in relation to its height above ground. It is for this reason that their importance is mainly confined to Band I.

At first sight it might appear that the finite distance effect must be wholly beneficial, since it provides a measure of gap filling. But if this is insufficient, the effect makes it more difficult to provide additional gap filling since it tends to reinforce any additional component of field provided for gap filling only in alternate minima, opposing it in the other minima. The task of calculating the performance of the aerial at short range is certainly increased. The best procedure is to compute the contribution to the field from each tier in amplitude and phase and sum all the contributions. Path lengths are best computed without approximation.

4. THE EFFECT OF REFLECTION AT THE GROUND

If the ground were not encumbered with buildings and if the height of the receiving aerial were known, the effect of ground reflection could be determined readily. Referring to Fig. 3, all that is necessary is to add, in the appropriate phases, the contributions arriving by the two paths shown. For the frequencies and angles of incidence with which we are concerned, it would be reasonable to assume a reflection coefficient of −1 at the ground.

In the case of the Crystal Palace aerial, to be described below, most of the receiving aerials affected by minima in the v.r.p. were below the height giving the

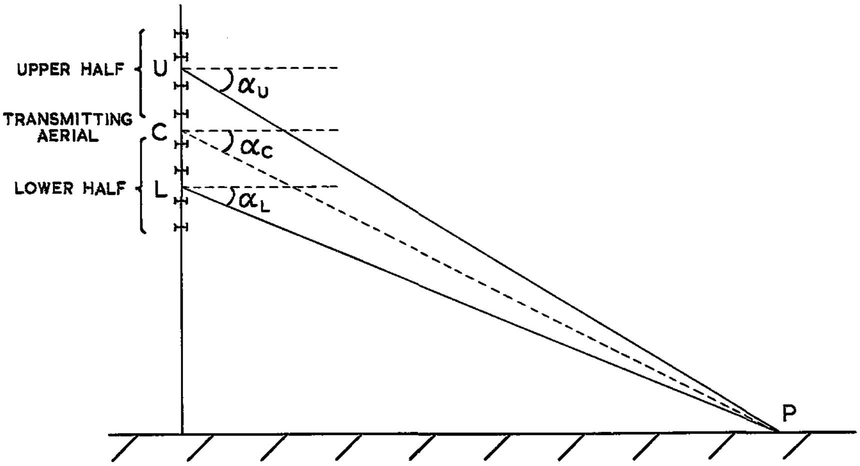


Fig. 2 - The effect of finite distance on the relative amplitudes and phases of the contributions from the halves of the aerial

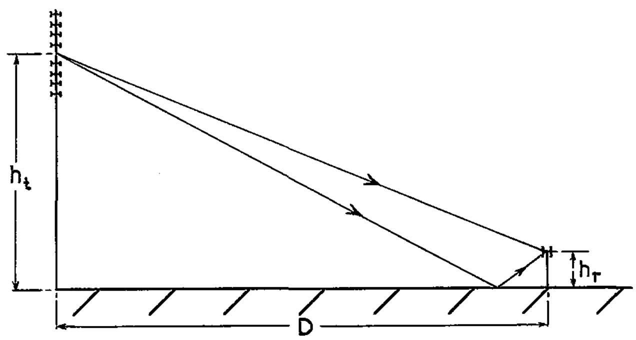


Fig. 3 - The effect of ground reflection on the received field strength

greatest received signal. (Referring to Fig. 3 this means that $h_t h_r/D < \lambda/4$.) In this region the effect of reflection is to enhance the relative contributions made to the received field by the upper parts of the transmitting aerial. It does not seem practicable to take this effect into account exactly but it is desirable to bear it in mind when considering any proposed method of gap filling. It may be remarked that the effect is opposite in sign to that discussed in Section 3, so that the two effects tend to cancel one another and one or more minima may not be filled in at all.

So far as was known when the Crystal Palace aerial was being designed, previous studies of gap filling had not taken into account ground reflection; it was decided to ignore it in view of the uncertain effect of the heavy concentration of buildings. As will appear, this decision proved incorrect.

5. THE CRYSTAL PALACE AERIAL

The television transmitting station at Crystal Palace has been described by McLean, Thomas and Rowden.[3] It was planned at a time when television was undergoing

evolution; broadcasting was being extended to higher frequency bands and the possibility of additional services was under consideration. It was, therefore, necessary to make provision for aerials for higher frequency bands before the requirements for these had crystallised. As a result, changes had to be made in the design of the Band I aerial when it was too late to re-design it *ab initio*. A brief account of these changes is necessary to explain its present form.

The site was restricted in area, necessitating the use of a self-supporting tower instead of the more usual stayed mast. It was originally planned that the tapering tower should be surmounted by two parallel-sided sections carrying an 8-tier Band I* aerial and an 8-tier Band III aerial, the latter to be capable of radiating two programmes. It was subsequently decided that the highest section of the tower must be capable of supporting an aerial for Band IV or V, projecting from the top. This change made it necessary to increase the cross-sections of the upper sections of the tower, and it was decided to accept the consequent impairment of the uniformity of the horizontal radiation pattern (h.r.p.) of the Band I aerial.

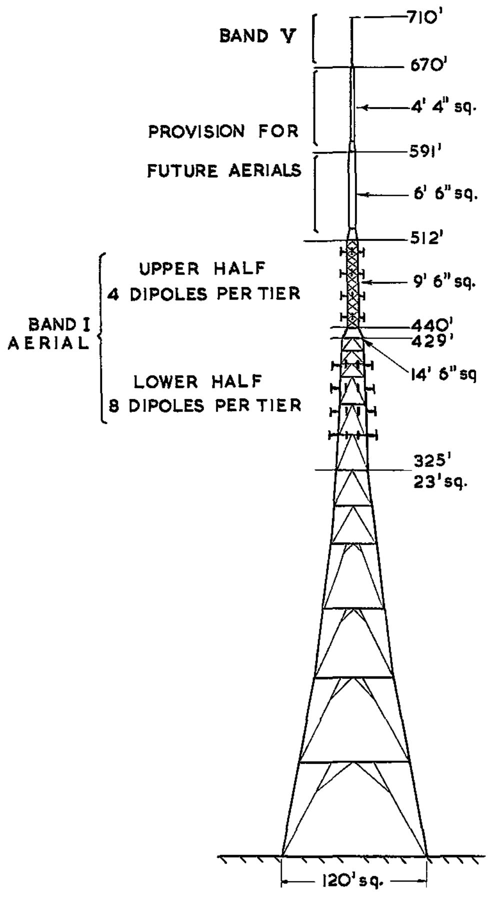


Fig. 4 - The Crystal Palace tower

Finally, it was decided to provide space for two 16-tier Band III aerials instead of one 8-tier aerial. This decision, which was made while the tower was in course of construction, entailed reducing the height of the Band I aerial by mounting its lower four tiers on the tapering support tower, and making the vertical spacing of the upper four tiers less than the optimum. Fig. 4 shows the general arrangement of the Band I aerial on the tower. The lower four tiers were entirely re-designed, but it was too late to make any change in the design of the upper four tiers. The final form of the aerial has been described by Wharton and Platts.[4]

The upper four tiers are mounted on a parallel-sided section 9 ft 6 in. (2·9 m) square between heights of 451 ft (138 m) and 505 ft (154 m) above ground level. The vertical separation between tiers is 0·825λ. Each tier consists of four skeletonised wide-band dipoles, spaced 0·2λ from the centre lines of the tower faces and fed in phase.

The lower four tiers are mounted on the tapering support tower between the levels 350 ft (107 m) and 409 ft (125 m) with a vertical separation of 0·9λ. Over this region the tower varies in cross-section from 21 ft (6·4 m) to 16 ft (4·9 m) square, and in order to

*At the time of writing the frequency limits of these bands are: Band I, 41-68 Mc/s; Band III, 174-216 Mc/s; Band IV, 470-585 Mc/s; Band V, 610-960 Mc/s.

obtain a sufficiently uniform h.r.p., it was necessary to employ eight dipoles in each tier. Two folded dipoles are mounted $0{\cdot}2\lambda$ from each face of the tower, with a separation of $0{\cdot}48\lambda$; this arrangement was found, by means of measurements on scaled models, to give the most uniform h.r.p.

6. HORIZONTAL RADIATION PATTERNS

The different forms of the upper and lower halves of the aerial result in h.r.p.s which differ in both amplitude and phase. The h.r.p. of the combined aerial is the vector sum of the contributions from the halves. Furthermore, since each half is fed from a separate feeder, the phasing of the inputs to the two halves can influence the h.r.p. of the combined aerial.

The h.r.p.s were deduced from model measurements at approximately one-tenth scale.[5] Two separate models were used, one representing one of the four tiers on the tapering support tower, the other one of the four tiers on the parallel-sided section above. A single tier of vertical dipoles was mounted on each model; the effect of the tapering form of the tower on the h.r.p.s of the lower four tiers was assessed by slightly changing the frequency (and hence the model scale factor) at the same time making the appropriate changes in the dipole positions. The amplitude and phase of the field from each model was measured relative to that at an arbitrary bearing by a null method using a General Radio Admittance Meter.[6]

The measured amplitude and phase of the h.r.p. of one tier of four dipoles representing the upper half of the aerial is shown in Fig. 5.

The model of the lower half of the aerial was used to determine the arrangement of dipoles which gave the most uniform h.r.p., the cross-section of the model mast corresponding to that of the full-size tower at the centre of the four tiers. In the arrangement chosen, the eight dipoles were mounted in pairs, $0{\cdot}2\lambda$ from the mast faces, with a separation of $0{\cdot}48\lambda$. These spacings were adopted for all four tiers without regard to the taper, which was found to have only little effect on the h.r.p. The measured h.r.p. of one tier of eight dipoles, shown in Fig. 6, was therefore taken to be the resultant pattern of the lower four tiers.

The h.r.p. of the two halves combined was deduced by adding the two fields at all bearings with a chosen phase difference. The phasing selected gave a compromise between the greatest mean gain (averaged over the h.r.p.) and the gain at the minima of the h.r.p. It was such that the contributions to the total field made by the halves of the aerial were in phase at bearings of 17° to the normals to the faces of the tower. This condition provided a means of setting up the full-scale aerial; a receiving point was established on the specified bearing and the relative phasing of the feeds to each half of the aerial adjusted for maximum signal.

Fig. 7 shows the h.r.p. of the combined aerial and of each half taken separately.

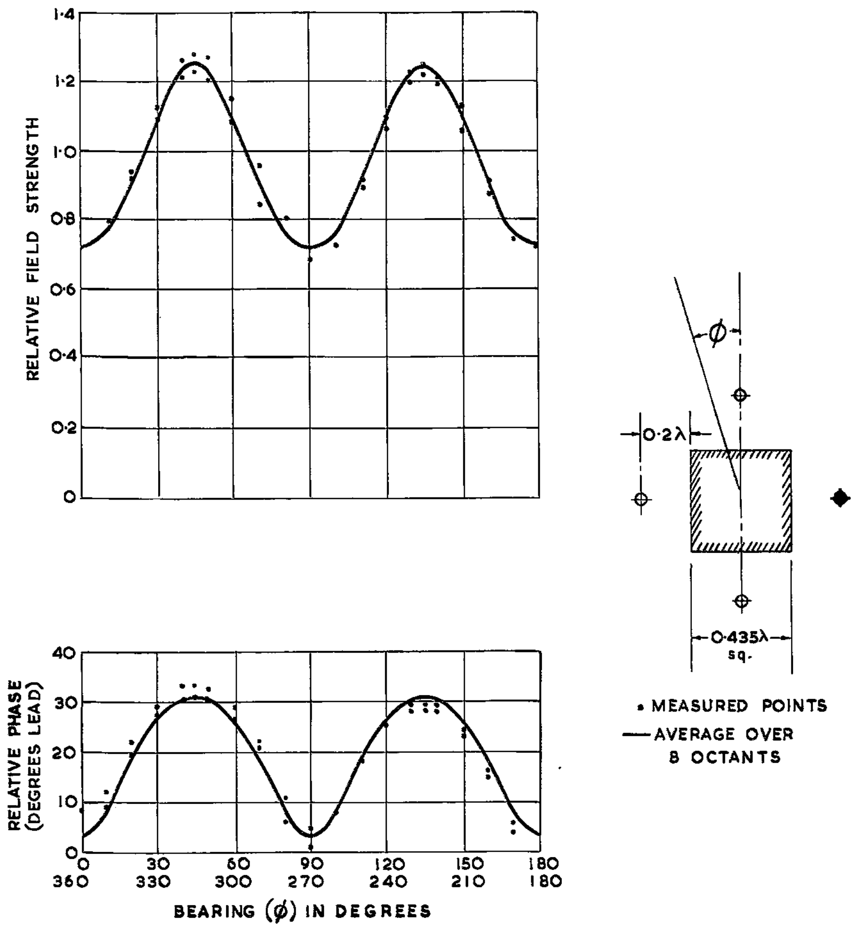


Fig. 5 - Measured h.r.p. of model aerial: upper four tiers

7. CALCULATION OF FIELD STRENGTH NEAR THE GROUND

7.1. Method of Calculation

The calculation of the variation of field near the transmitting station was complicated by the unusual form of the aerial. In order to get a result at all, it was necessary to make drastic approximations in applying theoretical formulae and to combine theoretical results with experimental data obtained from scale models. As a result, only an approximate determination of the minimum values of field strength and of the places at which they occurred could be expected.

The basic assumptions were as follows:

(a) Values of field were calculated initially for a horizontal plane passing through a point 30 ft (9·2 m) above the base of the mast. It was assumed that variations in ground level would merely displace the field strength contours radially in proportion to the depth of the surface of the ground below the centre of the aerial.

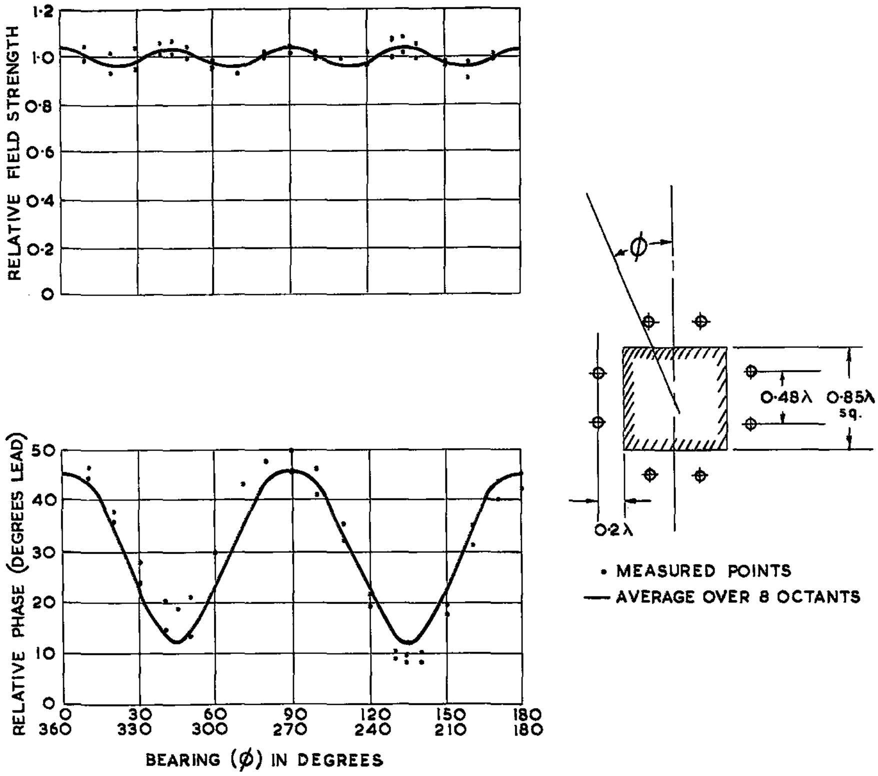


Fig. 6 - Measured h.r.p. of model aerial: lower four tiers

(b) Reflection at the ground was neglected, since the area is heavily built-up.

(c) The vertical radiation pattern of each tier was assumed to vary as $\sin\theta$, where θ is the angle to the vertical of the line joining the transmitting and receiving aerials.

(d) The vertical radiation pattern of the receiving aerial was assumed to vary as $\sin\theta$.

(e) The amplitudes and phases of the contributions from the eight tiers of the transmitting aerial were adjusted to take account of the amplitude and phase variations of the h.r.p.s, which were assumed to be independent of θ. It has already been stated that the mast taper had negligible effect on the variation of phase with azimuth.

(f) The mean phase of each contribution, averaged over the h.r.p., was corrected to take account of the non-uniformity of the tower. This correction, which was different for each of the lower four tiers and for the upper four tiers, was obtained from Carter's formulae[7] for the radiated fields of aerials round cylinders.

Values of the field were calculated for ten distances between 250 ft (76 m) and 5000 ft (1·52 km) at bearings of 0°, 17°, 30° and 45° to the normals to the mast

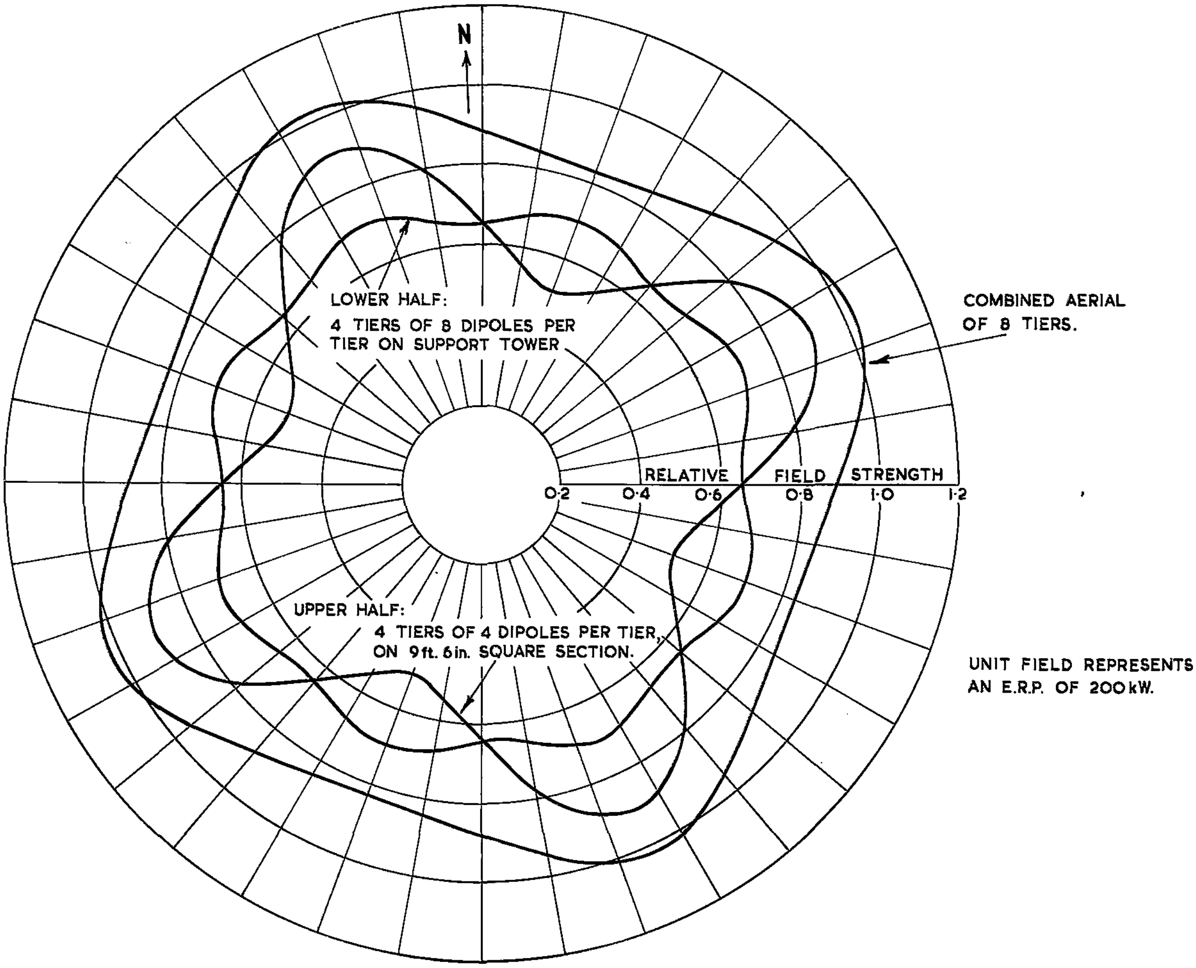


Fig. 7 - H.R.P.s of the final aerial

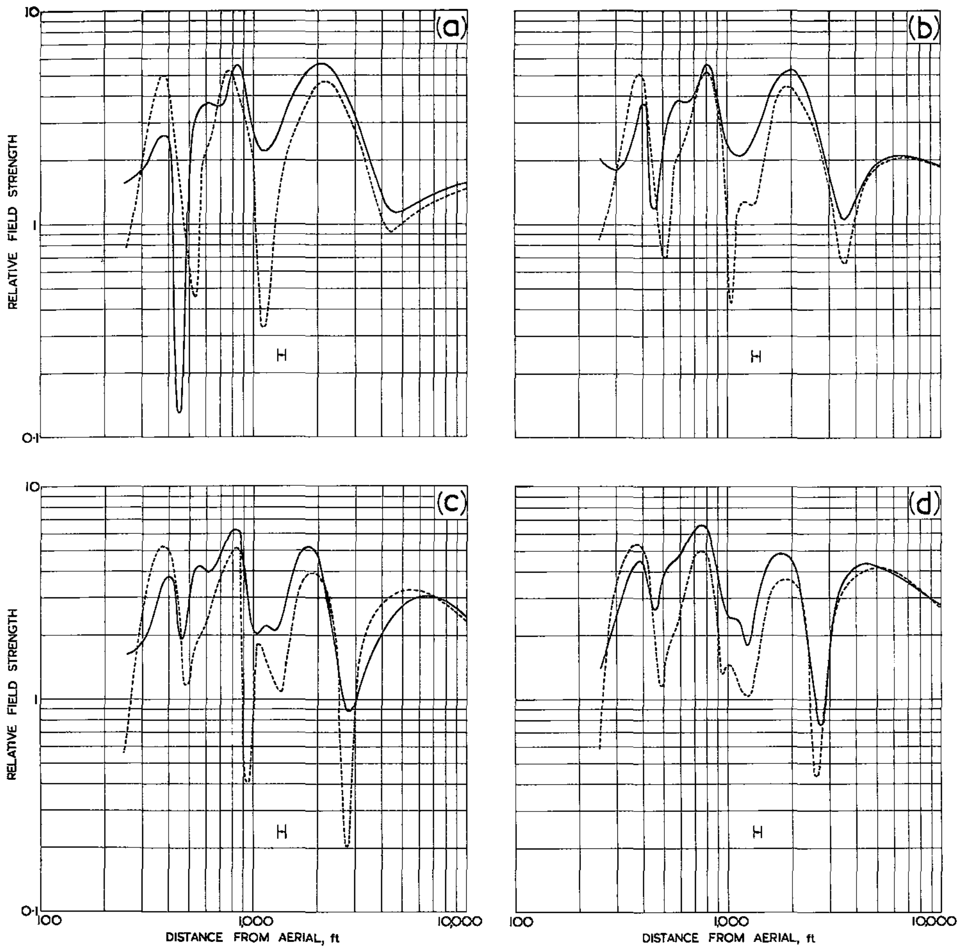
faces. Even with the simplifications made, the labour involved in the computation was considerable.

7.2. Performance in the Absence of Gap Filling

If reception in the immediate vicinity did not have to be considered, the greatest gain would be achieved by adjusting the phases of the radiating currents in the lower four tiers to bring their contributions to the distant field into phase. (Differences between the h.r.p.s of the lower four tiers are negligible). This entailed a phase difference of 17° between the currents in adjacent tiers, the phase in the upper tiers being advanced. As stated in Section 6, the h.r.p. of the upper four tiers differs in phase as well as in amplitude from that of the lower four tiers, so that it is only possible to obtain maximum gain in one particular direction. It has already been stated that the best compromise is achieved by phasing for maximum gain in directions at 17° to each face of the tower.

With the phases of the radiating currents controlled in the manner indicated above, the field strength near to the ground has been calculated as a function of the

distance for various directions, making the assumptions outlined in Section 7.1. The broken curves in Fig. 8 show these results for bearings of 0°, 17°, 30° and 45° to the faces.



(a) 0° BEARING TO TOWER FACE (b) 17° BEARING TO TOWER FACE
(c) 30° BEARING TO TOWER FACE (d) 45° BEARING TO TOWER FACE
-------FIELD STRENGTH WITHOUT GAP FILLING
———FIELD STRENGTH WITH GAP FILLING
H HORIZONTAL DISPLACEMENT OF CURVES FOR A FREQUENCY CHANGE OF 3 Mc/s

Fig. 8 - The effect of gap filling on the theoretical field strength near to the aerial

Logarithmic scales have been used in Fig. 8 in order to facilitate the estimation of the variation of field strength with frequency at any one point. It may be shown that the effect of a small change in frequency is mainly to move the curves bodily to the right or to the left, since the range of a particular feature of the curve varies in inverse proportion to the frequency. In Fig. 8 an indication is given of the displacement of the curves corresponding to the difference between the carrier frequency (45 Mc/s) and the extreme sideband frequency (42 Mc/s). The greatest variation with frequency occurs near the minima, where the curves are steep. The upper half of Fig. 9 is a contour map indicating the regions in which the extreme variation in field strength within the band 42-45 Mc/s is within given limits. It

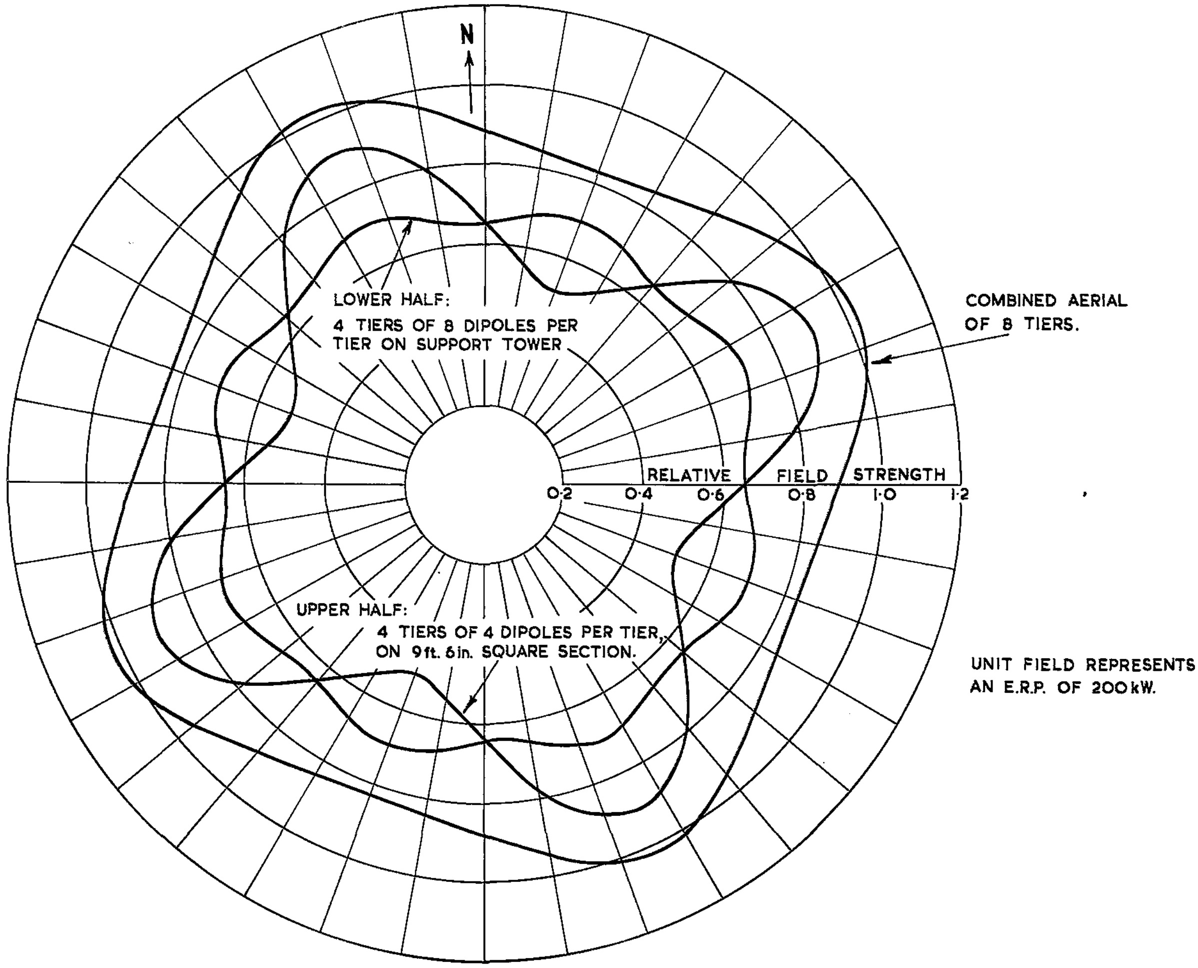


Fig. 7 - H.R.P.s of the final aerial

faces. Even with the simplifications made, the labour involved in the computation was considerable.

7.2. Performance in the Absence of Gap Filling

If reception in the immediate vicinity did not have to be considered, the greatest gain would be achieved by adjusting the phases of the radiating currents in the lower four tiers to bring their contributions to the distant field into phase. (Differences between the h.r.p.s of the lower four tiers are negligible). This entailed a phase difference of 17° between the currents in adjacent tiers, the phase in the upper tiers being advanced. As stated in Section 6, the h.r.p. of the upper four tiers differs in phase as well as in amplitude from that of the lower four tiers, so that it is only possible to obtain maximum gain in one particular direction. It has already been stated that the best compromise is achieved by phasing for maximum gain in directions at 17° to each face of the tower.

With the phases of the radiating currents controlled in the manner indicated above, the field strength near to the ground has been calculated as a function of the

distance for various directions, making the assumptions outlined in Section 7.1. The broken curves in Fig. 8 show these results for bearings of 0°, 17°, 30° and 45° to the faces.

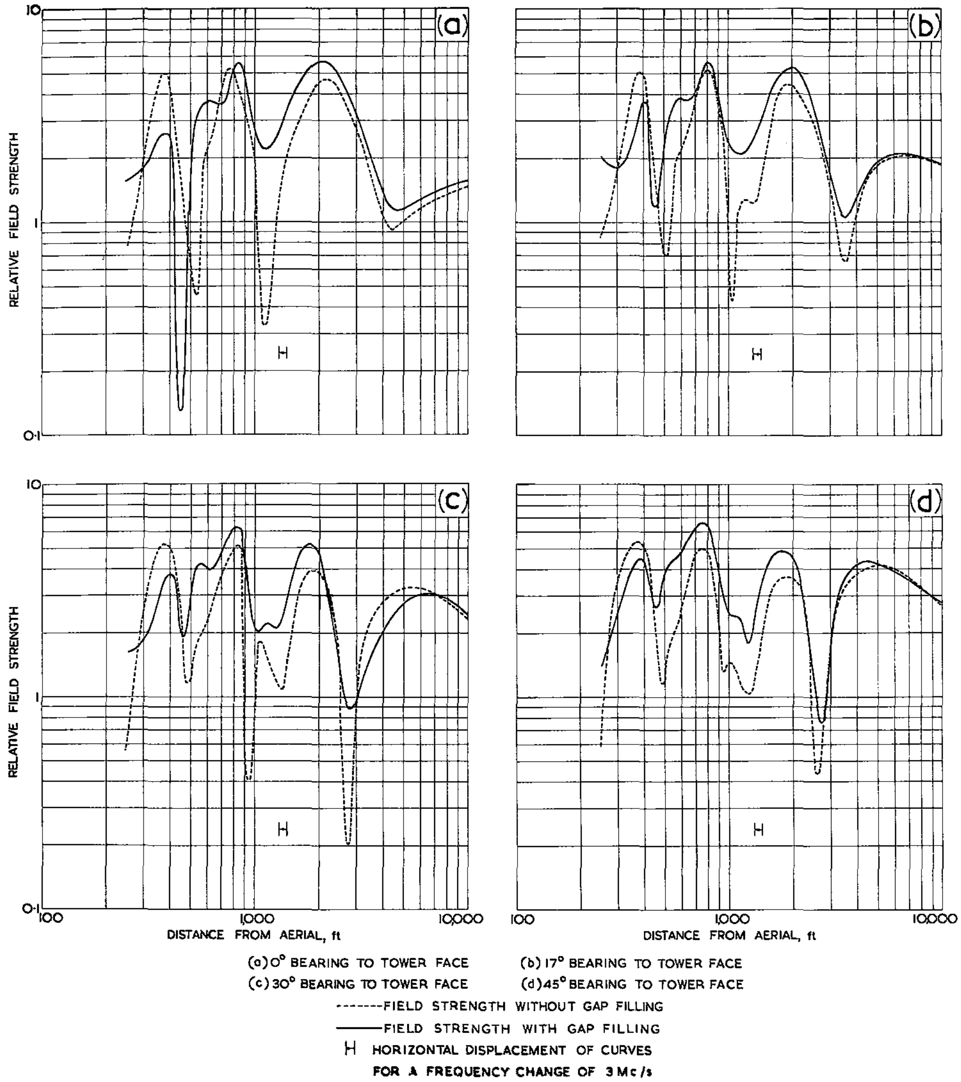


Fig. 8 - The effect of gap filling on the theoretical field strength near to the aerial

Logarithmic scales have been used in Fig. 8 in order to facilitate the estimation of the variation of field strength with frequency at any one point. It may be shown that the effect of a small change in frequency is mainly to move the curves bodily to the right or to the left, since the range of a particular feature of the curve varies in inverse proportion to the frequency. In Fig. 8 an indication is given of the displacement of the curves corresponding to the difference between the carrier frequency (45 Mc/s) and the extreme sideband frequency (42 Mc/s). The greatest variation with frequency occurs near the minima, where the curves are steep. The upper half of Fig. 9 is a contour map indicating the regions in which the extreme variation in field strength within the band 42-45 Mc/s is within given limits. It

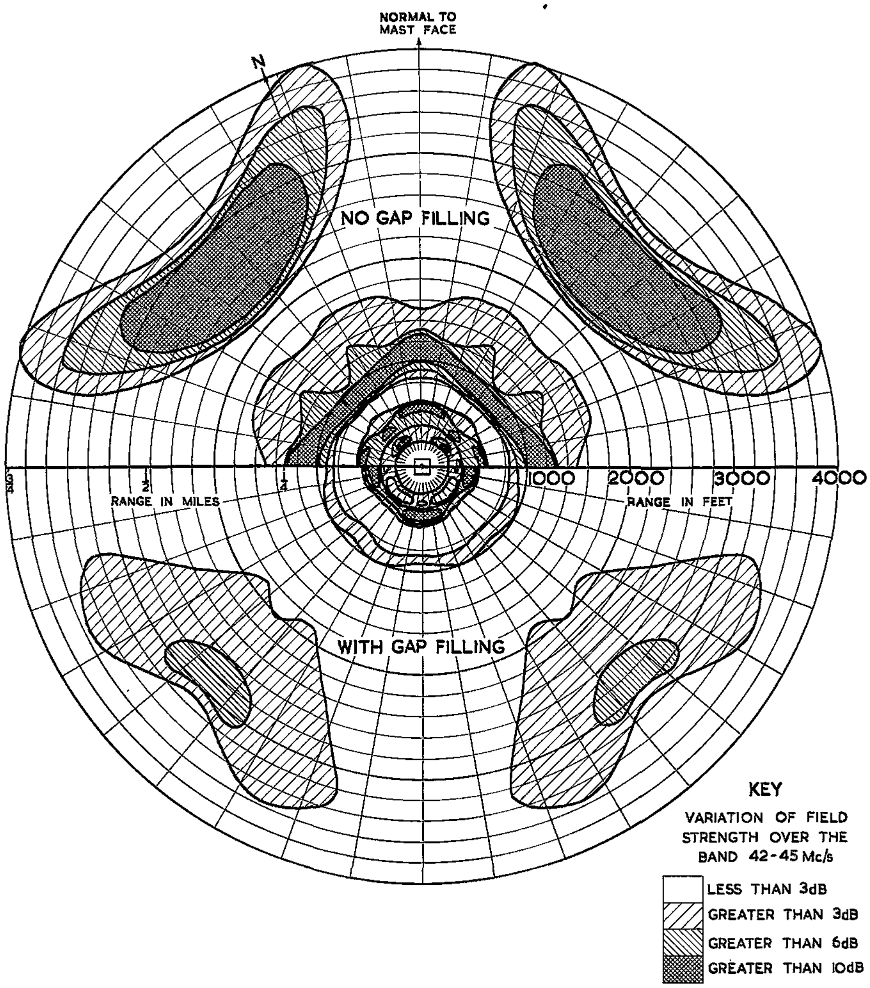
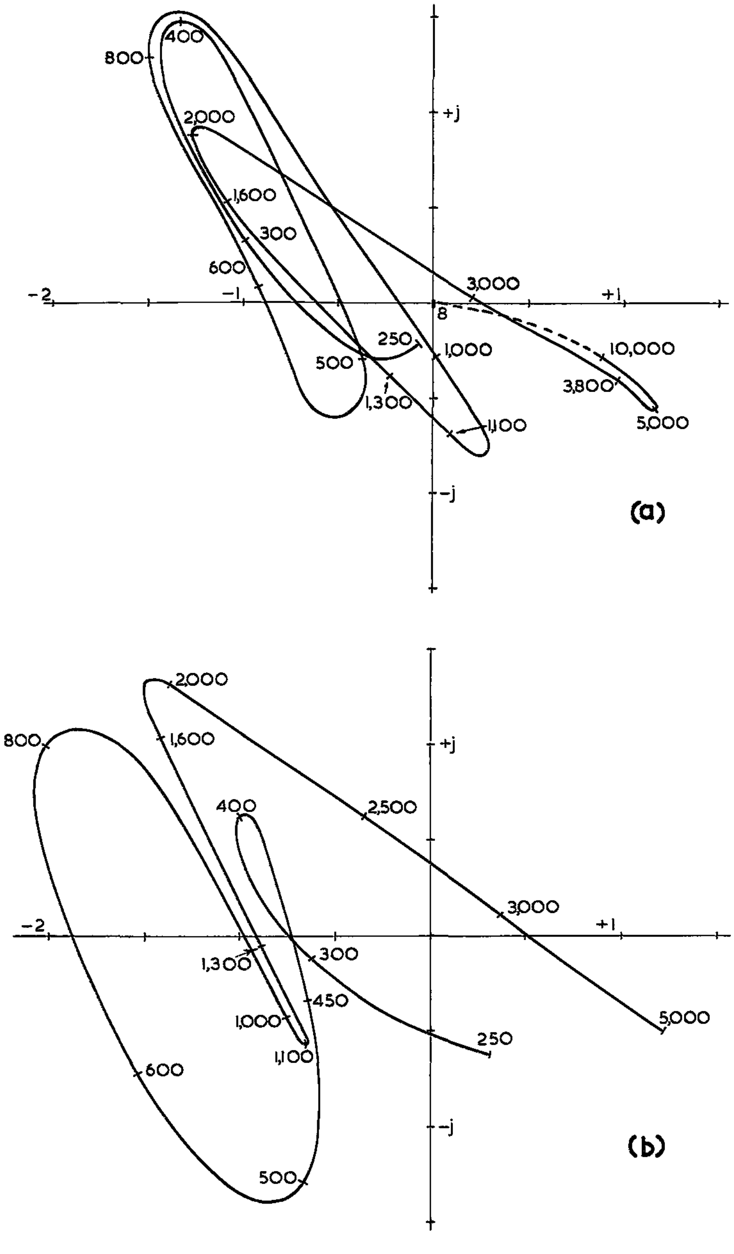


Fig. 9 - Effect of gap filling on reception near to the aerial

will be seen that there are considerable areas in which the variation is greater than 10 dB, and in these areas appreciable distortion would be expected. As a result of these calculations, it was decided that gap filling would be required.

It is difficult to determine the measures required to achieve sufficient gap filling using the curves in Fig. 8 only. A better guide is obtained by plotting field strength as a vector on the Argand diagram, taking as a phase reference a hypothetical source at the centre of the aerial system. As an example, Fig. 10(a) shows an Argand diagram plot for a bearing at 30° to the normal to a face.

If the effect of finite distance, which was discussed in Section 3, were negligible, as would be the case in Band IV or V, and if all the tiers of the aerial were identical and equally spaced, carrying equal radiating currents, the v.r.p. would be co-phased. In other words the locus shown in Fig. 10(a) would be described by a point oscillating on the real axis. The much more complex form of the locus in Fig. 10(a) is due to the effect of finite distance, the unequal spacing between tiers of the aerial and the unequal h.r.p.s of the halves of the aerial. These effects partially fill all the minima, and at the particular bearing considered in



(a) WITHOUT GAP FILLING
(b) WITH GAP FILLING

Fig. 10 - Complex relative field strength near aerial. Calculated for bearing 30° to tower face. Numbers on curves refer to distances in feet from base of aerial

Fig. 10(a) only two minima (having ranges of approximately 1000 ft (305 m) and 3000 ft (915 m)) appear to require further filling.

7.3. Initial Method of Gap Filling

The method initially adopted was determined by a process of trial and error in the method of calculation outlined above. A change in the radiating currents in one or more tiers was postulated and its effect assessed by regarding the change as due to the superposition of additional components of radiating currents. The field due to these components, which varied with distance, was added as a vector so as to modify the locus of the field on the Argand diagram.

It was necessary to bear certain practical considerations in mind. In the first place, it was undesirable to make any change in the feeding arrangements in the upper half of the aerial, since, owing to shortage of time, this feeder system was already being manufactured by a contractor when gap filling was being considered. As rigid feeders are used in the upper half, any change would be inconvenient. The elements of the lower half of the aerial are fed by semi-flexible cables, so that the phases of the radiating currents could readily be changed by altering lengths. In the second place, it was considered undesirable to alter the distribution of power between the halves of the aerial, since each half was to be fed independently from a separate transmitter. At the time it was thought that reliability would be impaired if any attempt were made to combine the outputs of the transmitters and redistribute the power between the halves of the aerial, since this procedure would entail the existence of certain components whose failure would completely interrupt the transmission.

With these considerations in mind, the method selected was to advance the phase of the 5th tier (number tiers from 1 to 8 from top to bottom of the aerial system) by 38° and to retard the phase of the 6th, 7th and 8th tiers by 12°. This change left the phase of the resultant field of the lower half of the aerial (tiers 5 to 8) unchanged. The phases of the radiating currents associated with the resulting contributions to the distant field at bearings of 17° to the faces of the tower are shown in Table 1 and compared with corresponding figures that would be obtained in the absence of gap filling.

TABLE 1

Relative phases of radiating currents and contributions to the distant field

Tier	Without gap filling		With gap filling	
	Radiating current	Distant field at 17° to tower faces	Radiating current	Distant field at 17° to tower faces
1 (top)	0°	0°	0°	0°
2	0°	0°	0°	0°
3	0°	0°	0°	0°
4	0°	0°	0°	0°
5	-72°	0°	-34°	+38°
6	-89°	0°	-101°	-12°
7	-106°	0°	-118°	-12°
8 (bottom)	-123°	0°	-135°	-12°

Resultant 0°

As already stated, the phase changes listed above were arrived at by a process of trial and error, but it is easy to see the manner in which the field strength in the outermost minimum, which is by far the most important, is increased. As stated in Section 3, the lower half of the aerial makes the greater contribution to the resultant field in the outermost minimum. Since the contributions from the two halves are in antiphase, the field strength will be increased if the inequality between the magnitudes of these contributions is increased. This is done by advancing the phase of the radiating current in the 5th tier (the highest tier in the lower half of the aerial), thereby tilting the maximum of the v.r.p. of the lower half downwards and increasing the contribution from the lower half.

The calculated effect of the phase changes is illustrated by the full-line curves in Fig. 8. It will be seen that the minima are less deep than those in the broken curves, apart from one region very close to the aerial. The improvement is illustrated in a different manner in Fig. 10(b), a plot of the field strength on the Argand diagram. In the lower half of Fig. 9, it is shown that the gap filling should appreciably reduce the variation of field strength at any one point over the band occupied by the transmission.

8. PERFORMANCE OF THE AERIAL WITH GAP FILLING

When the aerial system was first brought into service, some measurements of field strength and observations of picture quality were made in the immediate vicinity. The results indicated that the aerial was operating substantially as planned, but it is now realised that sufficient measurements were not made to reveal the worst receiving conditions that existed. Complaints were received from viewers in the immediate vicinity and it became apparent that the gap filling was inadequate. Reception conditions at distances up to 1·5 miles (2·4 km) were, therefore, investigated by making measurements of field strength simultaneously with observations of the received picture. Severe distortion was found in eight small areas (each about 400 yd (370 m) long and 100 yd (90 m) wide) about one mile (1·6 km) from the transmitting aerial in the outermost minimum of the v.r.p. The principal distortion was in the tone rendering, which was so non-linear that some pictures resembled photographic negatives. There was often difficulty in synchronization.

It was established that much of the distortion arose from differences between the modulation characteristics of the two transmitters. These differences were very small, since the transmitters had been built to a strict specification, framed with operation in parallel very much in mind. It would, however, have been impracticable to frame the specification sufficiently strictly to provide for regions in which the two transmitters would contribute in antiphase to the received signal, since any small departures from perfection, if markedly different as between one transmitter and another, would be magnified many times. For example, if one transmitter had only a slightly non-linear characteristic, the resultant would be much more non-linear. On the other hand, if the ratio of the amplitude of the picture signal to that of the synchronizing pulses were to differ slightly from one transmitter to another, the resultant could exhibit a very low picture amplitude, or even a negative picture. Alternatively, the synchronizing pulses in the resultant signal might be virtually non-existent. Unequal phase modulation, too slight to have any effect on the distant field where the contributions from the transmitters were nominally in

phase, could result in severe non-linear distortion when the contributions were in antiphase and approximately equal in magnitude. It was found that this last effect was the most difficult to overcome, since it was profoundly influenced by very small changes in the tuning of the r.f. input circuits of the modulated amplifiers of the transmitters. Fig. 11(a) is a photograph of a received picture showing typical distortion and may be compared with Fig. 11(b) which shows the test card being transmitted.

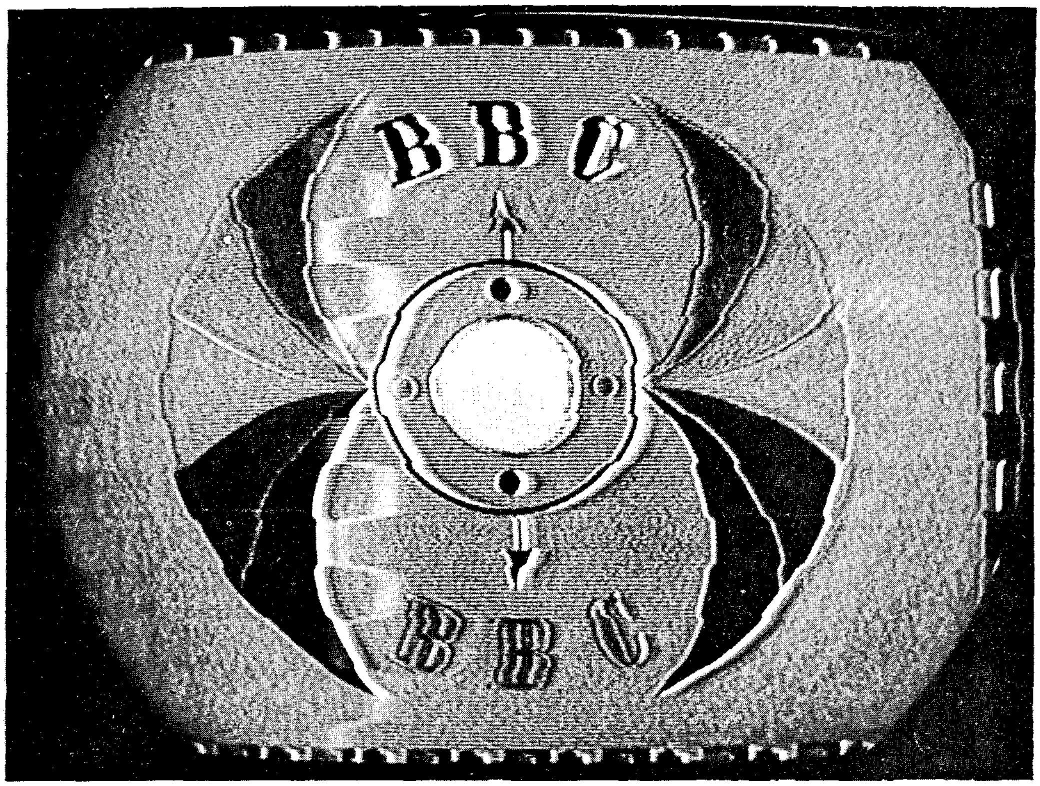
One method used to investigate the effects described above was to simulate the receiving conditions at the transmitting station by taking signals from the outputs of the transmitters, combining them in antiphase with a known amplitude difference and examining the picture produced by the resultant signal. It was found that a difference in amplitude of at least 3 dB was required to give acceptable picture quality. It was possible to reduce this figure by careful adjustment of the transmitters, but to maintain this condition from day to day would have imposed an excessive burden on the operating staff.

In order to determine how nearly the contributions from the two halves of the aerial were cancelling one another, the field strength was measured with the whole aerial in use and compared with that obtained with the lower half only in use. The smaller the ratio of the field strength from the whole aerial to that from half the aerial, the greater the degree of cancellation. When the whole aerial was used, it was energized by one transmitter only (this facility was available as an emergency condition[4]), since, for the purpose of investigating the performance of the aerial, it was desirable to eliminate any effect due to differences between the transmitters. Observations of picture quality were also made in this condition; the result corresponded to that which would be obtained if the transmitters could be made identical in performance.

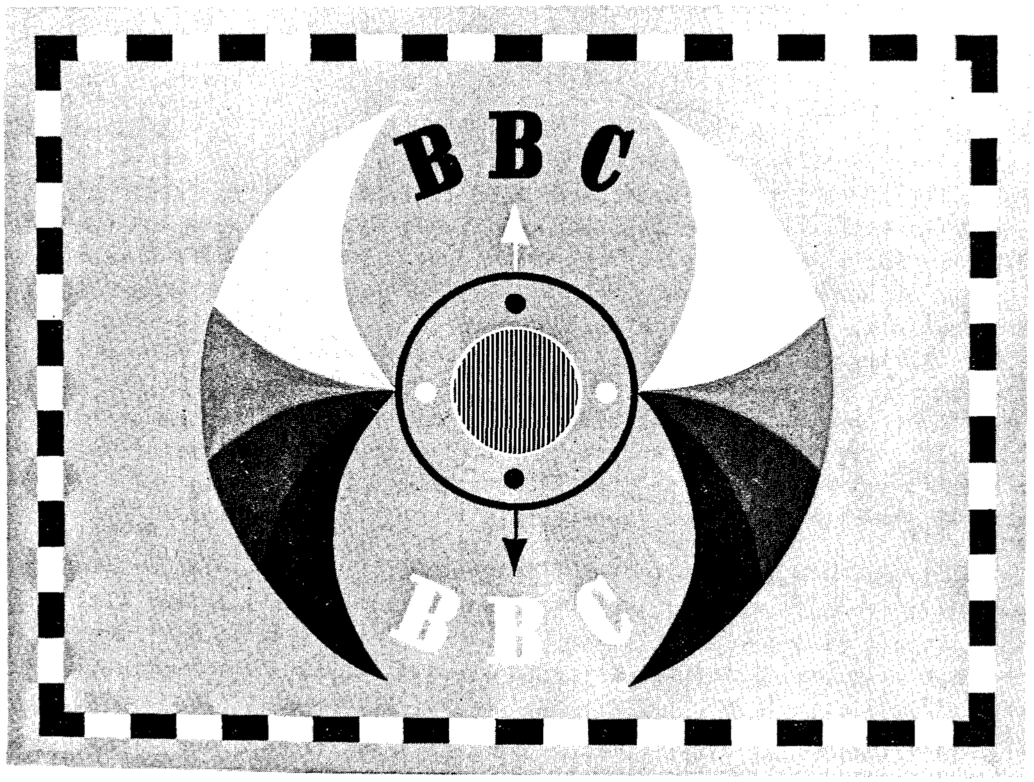
Figs. 12 and 13, respectively, show measured and theoretical ratios of the field from the whole aerial to that from the lower half at a height of 15 ft (4·6 m) above ground level. In Fig. 13 an approximate correction has been made for the ground contours by moving the field strength contours outwards in proportion to the difference in height between the ground at each point and the centre of the aerial system.

A comparison between Figs. 12 and 13 shows quite good qualitative agreement. Each of the four areas of low field strength has divided into two, but otherwise the positions of the minima are as predicted by theory. Nevertheless, the experimental results indicate that the contributions from the halves of the aerial can cancel one another to a greater degree than had been predicted. For example, the lowest ratio shown in Fig. 13 (theoretical), −12 dB, corresponds to contributions differing in amplitude by 2·5 dB, assuming them to be in antiphase. In the experimental contour map (Fig. 12) the minimum ratio is about −24 dB, corresponding to a difference of only 0·5 dB. By varying the power in one half of the aerial, it was established that the field from the lower half was the greater.

The picture quality, with only one transmitter in use, was generally satisfactory, but with the whole aerial in use some distortion of the type associated with non-uniform frequency response could be seen in small regions where cancellation was almost complete. Reception was generally satisfactory, except in the neighbourhood of the outermost minimum.



(a)



(b)

Fig. 11 - (a) Received picture showing typical distortion
(b) Transmitted test card

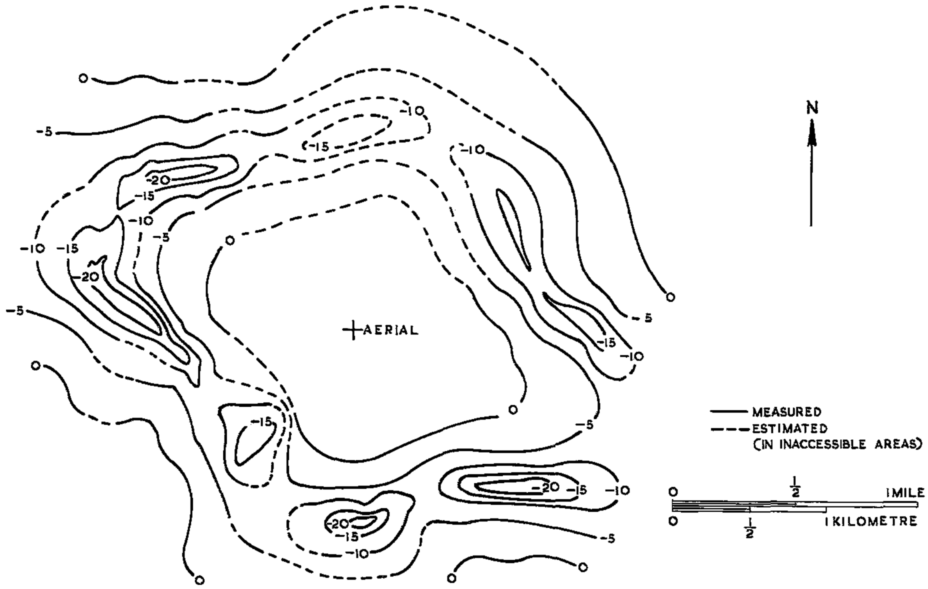


Fig. 12 - Measured field strength from whole aerial relative to that from single transmitter and lower half of aerial. Numbers on contours are dB values

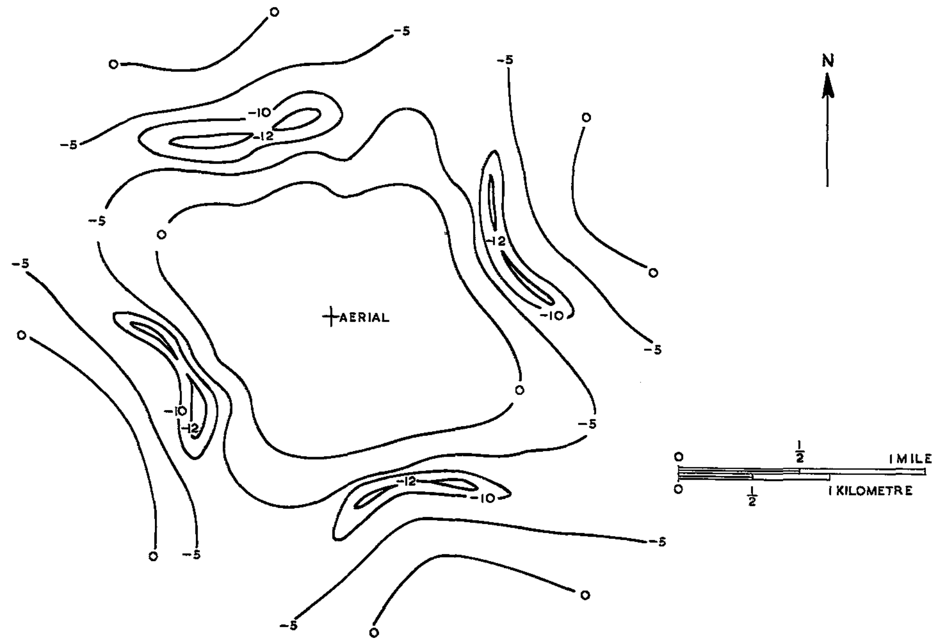


Fig. 13 - Theoretical field strength from whole aerial relative to that from single transmitter and lower half of aerial. No reflection at the ground. Numbers on contours are dB values

The conclusions may be summarized as follows. Even had the minima been filled in to the degree intended, it would have been impracticable to make the transmitters sufficiently similar in their characteristics to avoid distortion in regions where the contributions from the transmitters were in antiphase. But, in fact, the outermost minimum was not filled in to the degree expected.

Since there was no reason to suspect that the aerial was behaving other than as planned, it appeared possible that the inadequacy of the gap filling might arise from propagation effects, such as ground reflection and diffraction over buildings.

As stated in Section 4, reflection at the ground was neglected in the theoretical analysis since it was not thought possible to predict it in a built-up area. Calculations for a limited range of distances have, however, shown that, if a reflection coefficient of −1 had been assumed, the agreement between theoretical and experimental results would have been much closer.

Since the halves of the transmitting aerial are at different heights, their respective contributions will have different diffraction angles at an obstacle, that from the lower half suffering the greater attenuation. This could be particularly significant as regards the measurements of field strength, which were made with a relatively low receiving aerial.

In order to investigate these propagation effects fully it would be necessary to make extended observations with a higher receiving aerial. This was not practicable. At a few sites the receiving aerial was raised from 15 ft (4·6 m) to 30 ft (9·2 m); the variations of field strength indicated one or both effects to be significant but it was not possible to determine their relative importance.

9. MODIFICATIONS

In the light of the results of observations referred to above, it appeared impracticable to provide enough gap filling to overcome the effect of differences between the modulation characteristics of the transmitters when these were supplying separate halves of the aerial. It would not have been impossible to do so, but it would have been necessary to accept a serious loss of aerial gain in horizontal directions, that is, a reduction of field strength over the greater part of the service area. It was, therefore, decided to combine the outputs of the transmitters in a hybrid network, usually referred to in this application as a diplexer, and then divide the combined output between the halves of the aerial (Fig. 14). The effect of differences between the modulation characteristics of the transmitters would then be the same at all receiving points as it had been originally in the more distant parts of the service area.

This arrangement entailed some loss of reliability, since the diplexer was common to both halves of the transmitting installation, so that its failure would cause an interruption in transmission. This consideration was not, however, considered important, since passive networks fail rarely. It is true that the repair of a network designed for high power may take rather a long time, but it is not necessary to take this into account provided that the service can be restored in the meantime by the operation of switches.

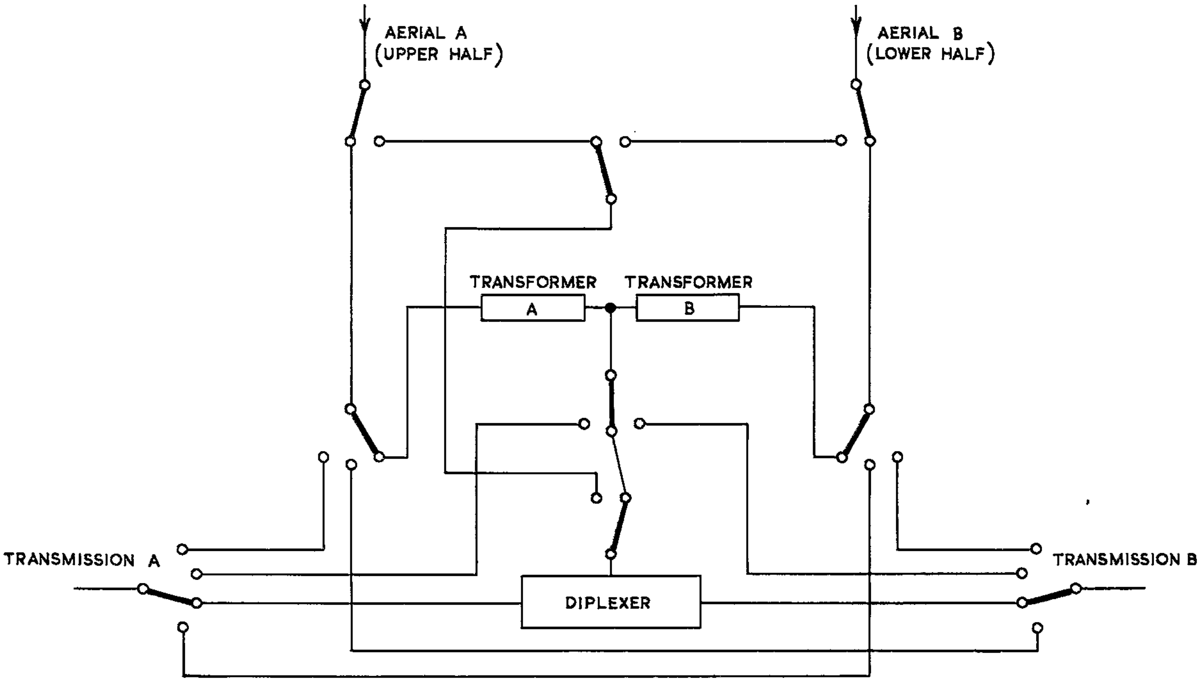


Fig. 14 - Modified arrangement of feeder switches

Although it was clear that the use of a diplexer would remove the cause of the great majority of complaints, it appeared desirable at the same time to mitigate the sharp minima shown in Fig. 12, where some distortion of the transmitted spectrum was apparent even when a single transmitter was used. This was easy to do, since for the first time it had become practicable to feed unequal powers to the two halves of the aerial.[8] It has already been stated that in these minima the contribution from the lower half of the aerial was predominant. It was, therefore, best to arrange for the greater part of the total power available to be fed to the lower half in order to accentuate this predominance.

Consideration of the measured depth and sharpness of the outermost minimum showed that, to reduce the variation of field strength over the video band to less than 3 dB, it would be necessary for the power in the lower half of the aerial to exceed that in the upper half by 2 dB. The effect on minima closer to the base of the aerial was calculated to be beneficial; in any case observations had shown that these were already adequately filled, apart from one less than 300 ft (91·5 m) from the tower where there are no dwelling-houses.

The unequal power division between the halves of the aerial results in a decrease of 0·1 dB in the e.r.p., averaged over all horizontal directions. Since the h.r.p.s of the halves differ, the radiation pattern of the whole aerial undergoes a small change, becoming slightly more uniform. Taking height-gain into account, the distant field is decreased by 0·3 dB for bearings of 45° to the tower faces, i.e. for the directions of the maxima of the h.r.p. For bearings normal to the tower faces there is negligible change in the distant field.

10. PERFORMANCE AFTER MODIFICATION

When the modifications to combine the outputs of the transmitters and divide their outputs in the required ratio were completed, the ratio of the power radiated by the upper half to that radiated by the lower half was measured. The measured ratio, 2·3 dB, was considered to be sufficiently close to the specified value of 2 dB.

The distant field produced by the modified arrangement was compared with that from the original, fully-split system at a site on a bearing of 10° to a tower face and some 11 miles (17·7 km) distant. Any change in field strength was less than 0·2 dB; the change predicted was less than 0·1 dB. Measurements of the distant field over a 180° range of bearings showed any change to be less than the measurement accuracy of ± 1 dB.

A survey of field strengths near the aerial gave results which are plotted in contour form in Fig. 15 on the same basis as Fig. 12. It may be seen by comparing the two figures that the minimum field strength has been increased by about 10 dB and now approximates to the condition originally intended, shown in Fig. 13. Fig. 16 is a contour map giving the absolute level of field strength.

Observations of the quality of reception with an omni-directional aerial at a height of 14 ft (4·3 m) above ground level showed this to be satisfactory almost everywhere. The only remaining defect was the presence of weak delayed images in some small areas of relatively low field strength. It was, however, considered that the use of a simple directional aerial mounted somewhat higher would, in every case, give adequate reception.

11. CONCLUSIONS

Experience gained at Crystal Palace has confirmed that when a transmitting aerial of high gain is erected in a populous area, great care is needed to ensure satisfactory reception in the immediate vicinity. The difficulty of doing so is greatly increased if the radiation patterns of the separate tiers of the aerial are not all the same. Nevertheless, these difficulties can be overcome and a satisfactory result obtained. Some sacrifice in the distant field is entailed, but this sacrifice can be restricted to a fraction of a decibel.

The use of entirely separate transmitters connected to different parts of the aerial is often the best and simplest method of ensuring transmissions uninterrupted by faults. Such a system should not, however, be used if there are receivers situated in the minima of the v.r.p. of the whole aerial, where contributions from the transmitters are received in antiphase. In this situation, it is better to combine the outputs of the transmitters in a hybrid unit before re-distributing it to parts of the aerial.

The problem of ensuring satisfactory reception in the immediate neighbourhood of a high-gain aerial will probably become more acute when Bands IV and V are used for television, since it will be necessary to use transmitting aerials of much higher gain. The methods used for gap filling at Crystal Palace will usually be

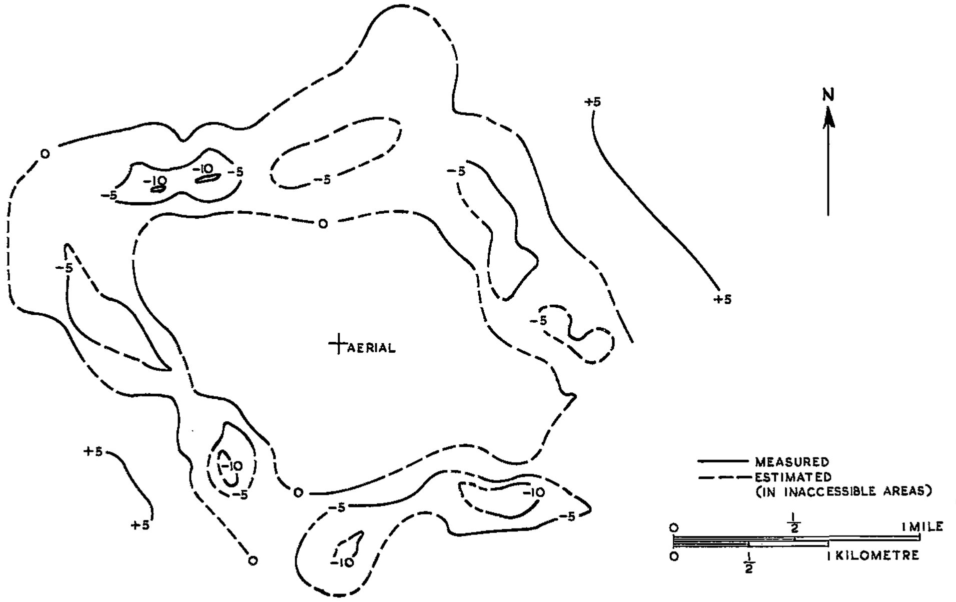


Fig. 15 - Measured field strength from modified condition relative to field strength from single transmitter and lower half of aerial. Numbers on contours are dB values

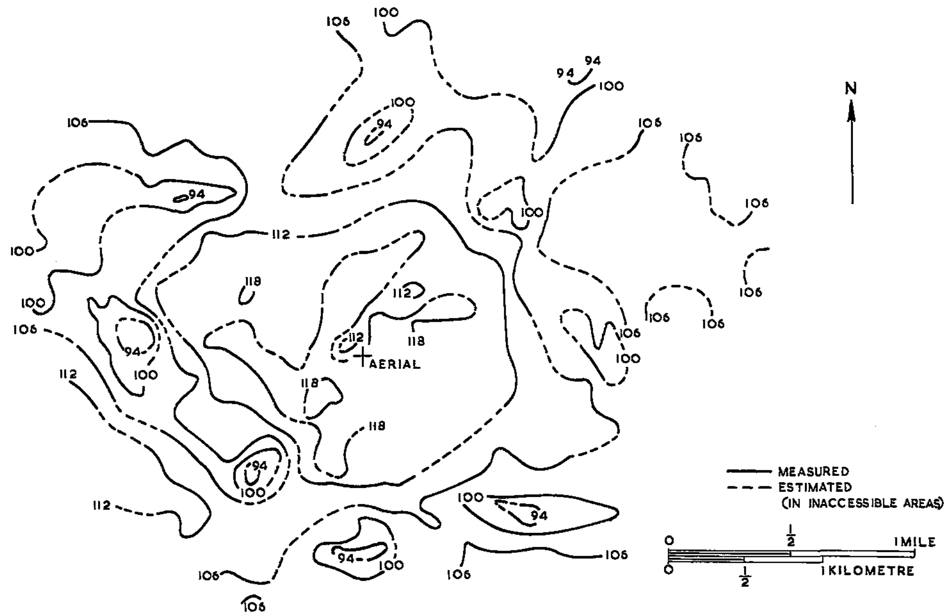


Fig. 16 - Measured field strength in modified condition. dB above 1 μV/m at 15 ft (4·6 m) a.g.l.

inadequate in Bands IV and V, and more elaborate procedures, such as have been employed in the U.S.A., will be necessary to give satisfactory local reception without undue sacrifice in the field strength at great distances. It may well be advisable to adjust the amplitudes and phases of the feeds to all the tiers separately in order to synthesise a specified v.r.p. Fortunately, some of the practical problems will be eased in Bands IV and V. The effect of finite distance, discussed in Section 3, will be negligible. Moreover, the fact that the transmitted band of frequencies is much narrower in relation to the carrier frequency can be used to simplify the design of the distribution feeder system.

12. ACKNOWLEDGMENTS

A number of the authors' colleagues took part in the work described. In particular, Messrs. R.V. Harvey and D.W. Osborne carried out much of the early theoretical work and devised the method of presentation used in Fig. 8. Computation was performed by Miss G.M. Oulton. Field strength measurements were undertaken by Mr. D.W. Taplin. The engineering design of the feeder system at Crystal Palace, including implementation of the gap filling measures, was carried out by the Planning and Installation Department, who also made detailed measurements of the linearity and phase modulation of the transmitters.

13. REFERENCES

1. "The Maximum Gain of Arrays of Stacked Vertical Aerials", Research Department Technical Memorandum E-1026, September 1952.

2. Kear, F.G. and Preston, J.G., "Control of Vertical Radiation Patterns of T.V. Transmitting Antennas", Proc. I.R.E., Vol. 42, No. 2, p. 402, February 1954.

3. McLean, F.C., Thomas, A.N. and Rowden, R.A., "The Crystal Palace Television Transmitting Station", Proc. I.E.E., Vol. 103, Part B, No. 11, p. 683, September 1956.

4. Wharton, W. and Platts, G.C., "The Crystal Palace Band I Television Transmitting Aerial", BBC Engineering Division Monograph No. 23, February 1959.

5. "Vertically-Polarized Band I Aerial for Crystal Palace: Radiation Patterns and Gain", Research Department Report E-061, Serial No. 1957/29.

6. "A Method of Amplitude and Phase Measurement in the V.H.F./U.H.F. Band", Research Department Report E-067, Serial No. 1959/1.

7. Carter, P.S., "Antenna Arrays Around Cylinders", Proc. I.R.E., Vol. 31, No. 12, p. 671, December 1943.

8. Newton, I., "Close-in Coverage with High-Gain V.H.F. Antennas", Broadcast News, Number 71, p. 44, September-October 1952.

MM